those components. That section is entitled "Signal Flow and Signal Processing in Transceiver/Switch 400." One of the major goals of this processing is to convert signals from the form provided by communication line 402 to the waveform, frequency band, and amplitude useful for successful communication across one of the extended pairs 405a-405c. The requirements for these characteristics are described in the section entitled "Transmission of Wideband Signals Over an Extended Pair."

Two other sections following are entitled "Signal Conversion and Switching in Transmitter/Switch 400" and "Transmission and Recovery of Signals from a Single Twisted Pair in a Bundle." Details of major processing components of transceiver/switch 400 are provided therein. Finally, details of signal processing with in local network interfaces 404 is described in the last section, which is entitled "Signal Processing at the Local Network Interface.

B. "Signal Flow and Signal Processing in Transceiver/Switch 400 (Fig. 22)

Following is a description of a general embodiment of transceiver/switch 400. Referring to Fig. 22, the major processing elements of transceiver/switch 400 are processor 418, signal separators 413a-413c master controller 415, low pass filters 474a-474c, and control signal processor 420. Processor 418 serves as the interface to communication line 402, and each signal separator 413a-413c (collectively, signal separators 413) serves as the interface to the corresponding one of extended pairs 405. One of the functions of processor 418 is to select, under the direction of master controller 415, video and other signals from communication line 402, to process those signals, and to feed them to signal separators 413. Another function of processor 418 is to receive video and other signals from signal separators 413, convert those signals to a form appropriate for transmission on line 402, and feed them to communication line 402. A third function is to receive

signals from any given one of signal separators 413, convert those signals, and to feed them to a different one of signal separators 413, thus establishing communication from one of local networks 411 to another.

Each of signal separators 413 is connected between one of extended pairs 405 and the corresponding one of twisted pairs 476. One of the two major functions of each of signal separators 413 is to transmit signals from processor 418 onto one of extended pairs 405. These signals are applied so that they transmit onto extended pairs 405 in the direction of local networks 411. A second purpose of each of signal separators 413 is to recover signals transmitting from one of local networks 411 over the corresponding one of extended pairs 405, and to provide these signals to processor 418. In some embodiments, signal separators 413 also convert telephone signals so that they transmit over extended pairs 405 at frequencies above voiceband.

Each of twisted pairs 476 connects to the "exchange" port of the corresponding one of signal separators 413. In Fig. 22, the "exchange" port is on the left side of signal separators 413, and the "local" port is on the right side. Signals provided by processor 418 to signal separators 413 transmit out the "local" port onto one of extended pairs 405 towards the associated one of local networks 411. Signals transmitting from local networks 411 to transceiver/switch 400 flow in the opposite direction. The various ports of signal separators 413 are shown in more detail in Fig. 29a. The details of signal routing within signal separators 413 are described below.

In contrast to the "local" port, only telephone signals flow through the "exchange" ports of signal separators 413. Telephone signals transmit over twisted pairs 476 in both directions, transmitting between local exchange 475 and the "exchange" ports, thus passing through

low-pass filters 474a-474c (collectively, low pass filters 474) during transmission.

Low-pass filters 474 connect in series on twisted pairs 476 to suppress the higher harmonics of telephone signals transmitting across them. This suppression prevents the higher harmonics of the telephone signals from local exchange 475 from reaching extended pairs 405, where they could possibly interfere with RF signals.

Signal flow between signal separators 413 and processor 418 is now described. There are two conductive paths connecting processor 418 with each of signal separators 413. Paths 478a-478c (collectively, paths 478) conduct signals transmitted by processor 418, and paths 479a-479c (collectively, paths 479) conduct signals transmitted by the associated one of signal separators 413.

The electrical signal, i.e. the voltage variations transmitted to each one of signal separators 413 from processor 418, may include several individual signals at different frequencies that are combined together onto the associated one of conductive paths 478. In response to commands sent from master controller 415, processor 418 determines the composition of each of these combined signals. After transmission to a particular one of signal separators 413, each combined signal continues on to transmit to the corresponding one of extended pairs 405.

Other than switching and filtering, no processing of the combined signal takes place after it leaves processor 418 until it reaches one of local network interfaces 404. Thus, the signal processing performed by processor 418 on the individual signals it selects and recovers from communication line 402 determines the waveform (e.g., AM or FM), frequency, and amplitude at which these individual signals are transmitted across pairs 405.

In the reverse direction, signals transmitted by RF transmitting devices 417 onto one of local networks 411

transmit to the corresponding one of signal separators 413. (Other devices can also transmit RF signals onto one of local networks 411. An example is any of video receivers 419, which transmit control signals.) The corresponding one of signal separators 413 recovers these signals and, except for control signals targeted for master controller 415, feeds them over the associated one of paths 479 to processor 418. These signals are received by processor 418 and applied to communication line 402. They may also be transmitted to any of local networks 411 that are different from the local network 411 of origin.

Control signals originated by subscribers are fed to local networks 411 within a specific frequency band, and are transmitted to master controller 415, as described below. This provides a method of communication between a subscriber and transceiver/switch 400, allowing the subscriber to control, among other things, the channels that are selected from communication line 402 for transmission to the local network 411 where the control signal originated. In a preferred embodiment, these signals are issued by an IR device 493 as infrared patterns which are detected by video receivers 419, converted to electrical signals, and fed onto the wiring. Other systems of feeding signals onto local network 411 within the particular frequency band can also suffice.

The control signals targeted for master controller 415 are received from local networks 411 by local network interfaces 404 which process them and apply them to extended pairs 405. These signals are recovered from pairs 405 by signal separators 413 and fed over the associated one of paths 477a-477c (collectively, paths 477) to control signal processor 420. Processor 420 processes these control signals and communicates them over path 420a to master controller 415.

Master controller 415 also receives (via control

signal processor 420) control signals that processor 418 recovers from communication line 402 and sends over path 420b. In response to these signals and to the control signals it receives from local networks 411, master controller 415 sends signals to processor 418 over links 446a-446e (collectively, links 446). Processor 418 determines the selection of signals from communication line 402 and the composition of the signals fed over extended pairs 405 to local networks 411 in response to signals from links 446.

C. Transmission of Wideband Signals over an Extended Pair

As described above, processor 418 selects signals from communication line 402 and converts them to the waveform, frequency, and energy level at which they are fed to extended pairs 405. These characteristics determine, to a large extent, the ability of video receivers 419 connected to local networks 411 to detect these signals and the ability of extended pairs 405 to conduct more than one signal at a time.

The nature of the communication medium that is the subject of this application presents two particular problems. One problem is that there is a significant possibility of crosstalk interference between the various signals on extended pairs 405. This possibility is high because telephone wires converging at a common point may run parallel and very close to each other for a long distance. This makes interference resulting from crossover of RF energy between the pairs likely. A second problem is that the usefulness of the system is related to the length of the longest path over which communication can succeed. This is a problem because communication bandwidth decreases as the length of a twisted pair communication line increases. (The issue of transmission length will be less important for communication within apartment houses and

office buildings than they will be for communication with separate residential structures in a neighborhood. This is mostly because the wires of many different networks in an apartment or office building often converge at a point less than 500 feet from those networks.)

In addition to these problems, there are also particular advantages to this medium. In particular, because extended pairs 405 connect directly between transceiver/switch 400 and local network interfaces 404, these wires encounter no splits and no connected telephone devices. Thus, signal splitting does not cause problems on extended pairs 405, and connected telephone devices will also not have an influence on transmission over those pairs.

U.S. Patent No. 5,010,399 and Parts I and II of this disclosure describe many of the relationships between the properties of a signal and its tendency to be attenuated and distorted during transmission across telephone wiring. As described therein, the maximum transmission length increases with decreasing frequency because of improvements in transmission characteristics. Specifically, attenuation, radiation, and the ability of the wiring to pick up (interfering) broadcast energy all decrease as transmission frequency is reduced. Also, crossover of energy between neighboring pairs decreases with decreasing frequency. Those applications also discuss spectral tilt, another undesirable byproduct of transmission over telephone lines.

Part I of this disclosure explains that FM video signals have a greater noise immunity than do AM video signals, i.e., the SNR after demodulation of an FM signal is higher than that of AM video signals if the frequency modulation process creates a signal with a wider bandwidth than the AM signal. As explained in Part I of this disclosure, the sensitivity advantage of FM video signals

over AM increases as the bandwidth of the FM signal increases.

The ability of FM signals to reject interference increases when the interfering signal is a second FM signal confined within the same channel. As explained in Part I of this disclosure, the minimum energy advantage that a receiver requires to reject a weaker but otherwise equivalent signal in the same channel is known as the "capture ratio", and is often significantly less than the minimum SNR necessary to avoid distortion by white noise. The exact capture ratio will depend on several factors, but the inventors estimate that the "capture ratio" of an FM NTSC video signal with a 15 Mhz wide bandwidth will typically be less than 10dB, allowing it to ignore interfering FM signals whose levels are suppressed by at least 10dB.

Using FM to transmit video has three disadvantages, however. One is that the tuning circuitry of common television sets expects to receive AM signals. This means that an extra signal conversion may be required before a picture is generated. Secondly, FM video electronic circuitry is more expensive. The third disadvantage is that a group of adjacent FM video channels will cover a wider band than a group of adjacent AM channels. In addition to occupying more spectral area, a band of adjacent FM channels will reach higher frequencies than a band of the same number of adjacent AM channels (assuming that both bands begin at the same frequency). Signals transmitting over FM channels, therefore, will generally suffer more from the problems associated with increasing frequency.

When processor 418 transmits several signals simultaneously across one of extended pairs 405, it assigns each signal to a separate frequency band, or channel. The energy of each signal will be confined within that band.

(Effectively, this "channelizes" that particular extended pair 405.) Additionally, processor 418 determines the waveform and energy level of each individual signal. On the basis of the considerations described above, a set of guidelines have been developed to aid in determining these characteristics for a given communication scenario. Some of the guidelines apply to transmission of signals of a general nature. Other guidelines will apply only to television signals. Still others will apply only to the specific situation of the communication of one or two video signals over especially long distances. These guidelines are disclosed in the following paragraphs (1-6).

1) Energy Level

Because RF signals that may be transmitted across telephone lines are relatively low in power, increasing signal level is not likely to cause a significant increase in cost, and is also not likely to cause problems of safety. Furthermore, maximizing the signal levels maximizes the SNR at the receiver. Thus, there are no benefits to lower signal levels, and the signal level should be set so that the resulting radiation falls just below governmental limits on the airborne radiation.

Because telephone wiring is unshielded, EMF radiation will result no matter how well the transmitting or receiving devices are shielded. Thus, these radiation levels will not significantly vary with any factor other than the signal level. This means that the radiation can be determined at the time of manufacture, avoiding the expense of providing for adjustable signal levels.

For example, following FCC procedures, the inventors fed a 22.45 Mhz NTSC video signal onto a telephone wire and measured the resulting radiation. It was found that at a conducted signal level of approximately 50dB mV, radiation from the wire would be just below the governmental limits of 30uV/M measured at 30 Meters. Thus, a level of 50dB mV

would be preferred for a transmitter that applies a 22.45 Mhz video signal to telephone wiring.

2) Adjacent Low-Frequency Channels

As described above, attenuation, radiation, crosstalk interference and reception of external interference all increase as frequency increases. This means that the signal with the highest frequency is most likely to have the lower SNR, and that overall communication success can be improved by lowering the frequency below which all signals are confined.

To minimize the highest frequency used for transmission, it is recommended that the first channel be placed as close to the voiceband as feasible, and that each succeeding channel be placed above and adjacent to the previous channel. The channels should be separated in frequency sufficiently, however, to allow clean separation at the receive end without excessive filtering costs.

3) Minimum Frequency

If AM is used to transmit video signals, it is preferred that the picture carrier of the first such channel be located above 4.25 Mhz. This frequency is chosen as a rough compromise between the following factors: a) transmission properties improve with lower frequencies; b) as described in Part I of this disclosure, the likelihood of distortion of AM signals caused by the phenomena of spectral tilt increases with decreasing picture carrier frequency below 5 Mhz; and c) there are certain advantages in arranging for transmission of several adjacent 6 Mhz AM NTSC video signals beginning with a signal whose picture carrier is at 4.45 Mhz. (One major advantage, which is described more fully in Part II of this disclosure, is that arranging video channels in this manner reduces the likelihood of interference from amateur radios.)

For FM transmission, it is preferred that the low

end of the first channel be 4 Mhz. This frequency is chosen as a rough compromise between the following considerations:

a) Transmission properties improve at lower frequencies;

b) Spectral tilt becomes more pronounced with increasing ratios between the highest and lowest frequencies of an FM signal. (the problem of the spectral tilt of FM signals is described in Part I of this disclosure);

c) lowering the low end of an FM band by 1 Mhz does not provide a significant decrease in the percentage reduction of the frequency of the high end. For example, moving the low end of a 15 Mhz channel from 3 Mhz to 2 Mhz only reduces the upper frequency by 5%, i.e. from 18 to 17 Mhz.

4) Bandwidth

Assume that "N" different signals are to be transmitted within adjacent channels, that the average width of the channel confining a signal is B Mhz, and that the low end of the lowest channel is k Mhz. Under these conditions, the high end of the channel highest in frequency is given by (Nb + k) Mhz. Thus, decreasing bandwidth decreases the maximum frequency.

Because of this, a preferred system when transmitting multiple NTSC video signals is to provide all signals using AM modulation within 6 Mhz channels distributed according to the NTSC standard. (I.e. a picture carrier 1.25 Mhz above the low end and a sound carrier .25 Mhz below the high end.) This arrangement is chosen because the bandwidth is relatively narrow, yet separation can be achieved using inexpensive filtering. This is the same arrangement that was chosen for airwave transmission of video shortly after the invention of television. The same justifications applied. Because of that standard, very inexpensive electronics exist for this type of channeling, providing another advantage.

The preferred lower end for the band of transmission over extended pairs 405 is defined by an AM signal with a

picture carrier of 4.45 Mhz. (The lower end of an NTSC video channel with a carrier of 4.45 is at 3.2 Mhz. This is because the bottom of the 6 Mhz channel is 1.25 Mhz below the picture carrier.) The advantages of providing adjacent AM signals with picture carriers spaced 6 Mhz apart and beginning at 4.45 Mhz are described in Part II of this disclosure. Also, a picture carrier of 4.45 Mhz is above the minimum frequency requirement of 4.25 Mhz suggested above.

Amplitude modulation is particularly adequate when only a small number of signals transmit over a short distance. As transmission distance increases, attenuation causes the SNR at the receiving end to drop. Similarly, as more channels are added to a wire pair of fixed length, one is forced to use higher frequencies, until the signal at the highest frequency is not received with an adequate SNR. (Note that capacity tightens up very rapidly with increasing frequencies because attenuation increases and at the same time the signals radiate more, forcing a reduction in the initial signal levels.)

A third phenomenon that can cause an inadequate received SNR is the presence of broadcast energy, which elevates the noise level. This is largely a function of the radio broadcasters in the area, but it is also related to frequency because telephone wiring acts as a more efficient antenna as the frequency of the broadcast signal increases.

<u>5a) Increasing Bandwidth to Counter Signal Attenuation</u>

When the attenuation of transmission or the presence of broadcast energy at the "unused" frequencies on a transmission line suppresses the SNR at the receive end below the minimum required for AM video, the proposed solution is to use frequency modulation with bandwidths significantly larger than 4 Mhz. (Four Mhz is the approximate bandwidth of an NTSC video signal at baseband.) As mentioned in Part I of this disclosure, receivers in FM

communication systems that use 15 Mhz of bandwidth per NTSC video signal are known to produce a demodulated signal that is approximately 10db higher than the SNR at its input. This is an improvement over AM systems because, in those systems, the SNR at the receiver output is equal to the SNR at the receiver input.

Following is an example. Assume that nine AM NTSC signals transmit across a path 400 feet long within adjacent 6 Mhz channels beginning at 6-12 Mhz and ending at 54-60 Mhz. Now assume that a signal of 45dB mV with a carrier at 61.25 Mhz, (corresponding to the channel between 60-66 Mhz), creates radiation just below the legal (FCC) limit when applied to telephone wiring. Because the attenuation on telephone wiring at 60 Mhz is approximately 12dB per 100 feet, the SNR of such a signal at the receive end of the above path should, theoretically, be -3 dB mV, or 3 dB below the minimum (0 dB mV) required for high quality video reception.

A solution is to transmit a 15 Mhz wide FM signal between 60 Mhz and 75 Mhz. The high end of this signal, being at 75 Mhz rather than 66 Mhz, will suffer greater attenuation, and will also radiate more energy. According to measurements performed by the inventors, however, the radiation difference will be negligible, (perhaps 1 dB), and the extra attenuation at 75 Mhz over the 400 foot path will be approximately 2 dB. Thus, the received level will be approximately -6 dB mV. If the SNR at the output of a 15 Mhz FM video receiver is approximately 10 dB higher than the SNR at the input, however, the SNR of the demodulated video signal will be 4dB, which is sufficient. Thus, transmission of an extra channel can be enhanced by using FM for the additional channel.

At higher frequencies, the 10dB advantage of a 15 Mhz FM signal may not be sufficient to overcome the extra attenuation. The solution, in that case, is to use wider

FM bandwidths which produce a greater SNR improvement at the receiver. This, of course, brings one to even higher frequencies more quickly with each channel that is added. Because of this, the inventors expect that higher frequencies will not be useful beyond some point, and certainly not beyond 1000 Mhz.

5b) Using FM to Counter Crosstalk

Within a bundle of unshielded telephone wire pairs, the amount of energy radiated by one pair that is received by another increases with frequency. This happens both because the radiation at a fixed signal level increases with frequency, and because the ability of the second wire pair to "pick up" the radiation also increases. This energy received by the second wire pair is known as "crosstalk" and the tendency of a particular medium to exhibit this type of interference is known as "crosstalk loss." That quantity is the ratio, in dB, between the signal directly applied to a communication line and the energy received from the radiation of a signal of equal strength fed to a neighboring line. The greater the "crosstalk loss," the less the interference.

At the voiceband frequencies of ordinary telephone signals, which are below 5 Khz, crosstalk loss is very high. Thus, the portion of the "noise" typically encountered by telephone signals that is related to crosstalk energy is very small. For this reason, telephone signals on neighboring wire pairs usually do not interfere with each other.

At frequencies above 1 Mhz, however, interference from crosstalk can be significant. Crosstalk loss will be affected by many different factors. According to measurements, made by the inventors, of several bundles of 12 pair and 25 pair telephone wires, crosstalk loss at 6 Mhz occasionally becomes less than 45 dB, while crosstalk loss above 50 Mhz rarely exceeds 40dB. These measurements

indicate that AM video signals, which can display the effects of interference at SNRs as low as 40dB, may suffer interference from crosstalk at even relatively low frequencies such as 6MHz.

FM signals, on the other hand, have impressive resistance to crosstalk interference because of their very low "capture ratios." As stated in Part I of this disclosure, the inventors estimate that receivers that process FM video signals with bandwidths of 15 Mhz or more can reject interference from any FM signals transmitting in the same channel if the level of the interfering signal is weaker by 10dB or more. Thus, it would appear that FM video signals will not encounter crosstalk interference until at least 50 Mhz, and the use of FM at the very lowest video channel may be indicated.

5c) Using Secondary Pairs for Additional Channels

As mentioned above, there is an upper limit to the frequencies that can be useful for transmission of signals across a transmission path of a given length. Thus, the number of signals that can transmit over an extended pair to a given local network is limited.

In most apartment buildings, however, several extended pairs service (i.e. are dedicated to) each apartment unit. Each of these pairs typically branches off to connect to each of the jacks in the unit. Typically, one of these pairs conducts the signals for the primary telephone service to that unit. Additional pairs are left empty unless and until secondary telephone lines are requested. Thus, apartment units are typically serviced by more than one of extended pairs 405 and, correspondingly, more than one of local networks 411.

An example is where red, green, black, and yellow conductors connect at each jack in a unit and also extend down to the point of concentration in the basement of the building. The red and green wires in the unit constitute

one of local networks 411, and the yellow and black wires constitute a second of local networks 411. The lengths of these wires that extend down to the basement of the apartment building constitute the extended pairs 405.

If more signals are required than can be accommodated by a single extended pair, the extra wires present an opportunity. As described earlier, the twisted pairs connecting to the same unit may be bundled more tightly together than arbitrary pairs in the same bundle, potentially increasing crosstalk interference. If this increase is not dramatic, however, the techniques to avoid crosstalk described above will be sufficient to prevent crosstalk interference between signals on these two pairs that serve the same unit, preserving the opportunity for transmission of additional signals.

Indeed, using an additional pair for the second channel provides the economy that fewer frequency bands are required to transmit a given number of signals. For example, assume that transmitting two signals can be done by using FM within the channels between 6-18 Mhz and 18-30 Mhz, and that at most two signals are required by any unit. It may be more economical, in this case, to provide the second signal within the 6-18 Mhz channel but on a secondary pair. This allows video receivers 419 to receive either signal using only the electronics necessary to tune the 6-18 Mhz channel. Switching from one signal to the other is simply a matter of switching between wire pairs.

Transceiver/switch 400 can enjoy a similar economy. Using the example above, transceiver/switch 400 need only be equipped to transmit within the 6-18 Mhz channel to satisfy the system requirements.

<u>5d) Transmitting over Unused VHF Channels</u>

As described in Part I of this disclosure, systems that transmit signals at unused VHF television channels are very reliable because they enjoy the advantage of total

immunity (as a practical matter) from broadcast interference. It was further described how the relatively high attenuation suffered by signals transmitting at those relatively high frequencies can be overcome, in some circumstances, by using low-pass filters to remove all of the attenuative affects of all telephone devices connected to the wiring.

Because cable TV companies consider reliability an extremely important part of their delivery systems, use of unused VHF channels within the systems described herein is an interesting option. For example, a cable company considering distribution of AM signals through an apartment unit within 6 Mhz channels below 30 Mhz may be concerned that an amateur radio enthusiast can erect an antenna nearby and broadcast at the 10 meter, 15 meter, 20 meter, and 30 meter bands, all of which are below 30 Mhz.

One of the problems of using unused television broadcast channels in the systems that are the subject of this application, however, is that the wires leading to the various units may be bundled tightly together, causing the crosstalk problems described above. Crosstalk interference is even more likely to occur because crosstalk increases with frequency, and unused TV channels are at relatively high frequencies. Also, because adjacent unused channels are not typical, only 6 Mhz is available per channel, preventing the use of FM, which is more resistant to crosstalk.

In many apartment buildings, however, the wires providing telephone signals to an individual unit are often not bundled tightly together with wires leading to other units. This is especially common for the wires that lead from a "wiring closet" that serves as a concentration point for the various units on the same floor. Often, separate bundles of four or more conductors lead from this point to each apartment unit. Because the bundles are separate,

crosstalk will be negligible. Because they need not traverse between floors, moreover, these bundles are relatively short in length, decreasing the likelihood that they will exceed the relatively short transmission length limits imposed by unused television channels.

The combination of short path lengths and separate bundles is an ideal configuration for transmitting over the unused television channels. Following is an example. Assume a five story apartment building in New York City includes five units on each floor, and that four wires service each of the units on a floor. Assume further that the conductors from each unit are bundled together and lead to a wiring closet on the same floor. Inside each wiring closet, transceiver/switch 400 is installed and connected to the cable TV trunk which is brought to each closet. (Leading this cable to each closet is the only wire installation required.) In New York City, VHF channels 2, 4, and 5 are used, making VHF channels 3 and 6 open for transmission. Using the technology described herein, transceiver/switch 400 feeds two different signals, one at VHF channel 3 and one at VHF channel 6, onto one of the twisted pairs leading to each unit. Note that the second twisted pair will typically not be useful because it is bundled too closely to the first pair.

6) Transmission of Video using Compressed Digital Signals (Fig. 35)

Currently, extensive effort is focused on developing methods to compress digital representations of NTSC video signals. These efforts have reached the point where it appears that the digital bitstream representing an NTSC video signal can be compressed sufficiently so that it can be transmitted within a channel narrower than the 4 Mhz occupied by the video portion of the original analog NTSC signal. In other words, the digital bitstream can be expressed, using techniques such as pulse code modulation (PCM), as an analog signal with a bandwidth less than 4

Mhz. Furthermore, the SNR required for accurate reception of this signal and recreation of the compressed bitstream is less, potentially, than the SNR required for quality reception of FM video signals. Also, the digital signal has similar resistance to crosstalk interference. Thus, it appears that video signals can be communicated more efficiently across networks of the particular type discussed herein if they are in digital form. The drawback of digital transmission of video, of course, is the expense of digitization and compression of the video signal at the transmit end, and the expense of the inverse processes at the receive end. Because it is expected that compression circuitry will dramatically decrease in price, techniques to transmit compressed digital video signals are included in a later section of this disclosure and shown in Fig. 35.

D. Two-Way Transmission of Video Signals

The guidelines for choosing transmission bands and modulation methods for transmitting video signals from transceiver/switch 400 to local networks 411 also apply for transmission in the opposite direction. An extra consideration arises, however, when transmission in both directions takes place simultaneously. The consideration is a form of interference sometimes called "nearend crosstalk." This interference can occur when signals are fed to a wire pair at one end while signals transmitting at the same frequencies are received from a neighboring pair (in the same bundle) at the same end. To see why this type of situation is likely to cause interference, consider the following example.

Assume that transceiver/switch 400 modulates a first video signal using AM with a carrier frequency of 8 Mhz and feeds it onto extended pair 405a, and that local network interface 404b modulates a second video signal using AM and a carrier at the same frequency and feeds it onto extended pair 405b towards transceiver/switch 400. Assume further

that the attenuation of transmission at 8 Mhz is 2 dB per 100 feet, and the paths, i.e. pairs 405a and 405b, are 1000 feet long.

Now consider the signals present at transceiver/switch 400 on pair 405b. The level of the first signal is simply that produced by transceiver/switch 400 minus the loss in energy as it leaks from pair 405a onto pair 405b. The level of the second signal, which is the signal of interest on 405b, is 20 dB lower than that produced by interface 404b because of the attenuation of transmission. Thus, if the second signal is an AM video signal, interference will occur unless the first signal loses at least 60dB crossing from 405a to 405b. Experiments performed by the inventors indicate that, in typical situations and at frequencies above 5 Mhz, the crossover loss is likely to be much less than that, perhaps even low enough to cause interference with FM video signals.

The solution proposed herein is to ensure that the bands used for transmission in the "forward" direction, i.e. from transceiver/switch 400 to local networks 411, are the same for each of extended pairs 405. In other words, the frequencies used by signals transmitting along extended pair 405a from transceiver/switch 400 to local network 411a are not also used by signals transmitting over extended pair 405b in the reverse direction, i.e. from local network 411b to transceiver/switch 400.

As described above, a very important application of the techniques disclosed herein is the one-way distribution of cable TV signals. In these types of applications, wideband video signals are transmitted from transceiver/switch 400 (i.e.,the point of convergence) to local networks 411, and control signals, which will be narrowband because they have very small information content, transmit in the opposite direction to provide the

selection mechanism.

In these situations, where only a very narrow (e.g. less than .5 Mhz) signal transmits towards transceiver/switch 400, it is preferred that the narrowband signal transmit just above voiceband, below the wideband signals. This reduces the expense of filtering, because the cost of a filter is inversely proportional to its "fractional bandwidth," which is the bandwidth divided by the center frequency. Thus, a .5 Mhz filter at 1 Mhz, for example, has a fractional bandwidth of .5, and the fractional bandwidth of a 6 Mhz video signal at 4 Mhz is 1.5. Reversing the frequency order of the narrowband signal and the video signal, i.e., placing the narrowband signal at 7 Mhz and the video signal at 3 Mhz, makes these fractional bandwidths .07 and 2, dramatically decreasing the fractional bandwidth of the narrowband signal, without significantly changing that of the video signal.

E. Transmitting a Single Video Signal over Long Transmission Lengths (Figs. 23A-23C)

When transmission lengths are longer than 1000 feet, transmission problems may be encountered even at frequencies below 10 Mhz. In these types of situations, use of extended pairs 405 to communicate multiple signals over a large frequency range may not be feasible. A system that communicates only a single video signal, however, can still be very useful in many important applications.

To provide for communication of a single video signal under circumstances of long transmission length, three different sets of specific waveform/frequency combinations are shown in Figs. 23a-23c and disclosed below. To gain extra transmission length, each of these uses frequencies below the lower limits suggested above.

Each of these techniques has advantages and disadvantages vis-a-vis the other two. One technique is to transmit the signal amplitude modulated at a frequency

slightly above voiceband (Fig. 23a). A second technique is transmit an unmodulated signal at baseband (Fig. 23b). The third technique is to transmit the signal frequency modulated within a band having a low end of approximately 3 Mhz (Fig. 23c).

One of the applications where communication of a single video signal can be important is in transmitting cable TV signals over extended pairs 405. In this case, provision is made for the user to select the signal to be transmitted. Methods of encoding low data rate bitstreams, e.g., 100 bits per second, into signals with narrow bandwidths, e.g., less than .5 Mhz, that can tolerate very low SNR levels at the receiver input are well known. Thus, it will be appreciated that the "selection" (i.e., control) signal can normally be transmitted at frequencies above the video signals in each of the techniques described below, and still tolerate the added attenuation of those higher frequencies.

Alternatively, in the case of the distributions shown in Figs. 23a and 23c, there is "room" to transmit a narrow band control signal between the voiceband and the video signal. Because placing narrowband signals near the voiceband reduces filtering costs, as described above, this is a preferred method of transmitting these signals. Thus, Figs. 23a and 23c allocate a small part of the spectrum between the voiceband and the video signal to these selection signals.

The distribution shown in Fig. 23b does not allow this because the video signal extends down to baseband. In this situation, a preferred method is to transmit the narrowband "selection signal" in a frequency band above both the video information and the telephone signals.

<u>1) Amplitude Modulation within a Low-Frequency Channel (Fig. 23a)</u>

In the first technique, processor 418 converts each video signal selected from communication line 402 to an AM

signal whose carrier frequency is below 3 Mhz, and is preferably closer to 1 Mhz. To prevent interference with telephone signals, the lower sideband of this signal, known as the lower vestigial sideband, is suppressed to substantially eliminate the energy in the voiceband.

Fig. 23a shows the spectrum of such a signal. The carrier frequency is 1.25 Mhz, with the lower sideband substantially suppressed below 1 Mhz. The 1.25 Mhz frequency is chosen as a compromise between the transmission advantages of lower frequencies (which are described in U.S. Patent No. 5,010,399 and Part I of this disclosure,) the disadvantages of lower frequencies (which are described below), and a particular advantage of the specific frequency of 1.25 Mhz (described in the next paragraph).

One of the disadvantages of lower frequencies is that the filtering that separates these signals from voiceband signals is more expensive because of the sharp cutoff required between the upper end of the voiceband and 1 Mhz. A second disadvantage is that the harmonics of the telephone signals at lower frequencies are stronger, meaning that stronger filtering of the harmonics is required to protect against interference from these signals. A third disadvantage is that the modulation electronics become more expensive as the picture carrier approaches DC. The particular advantage of the 1.25 Mhz picture carrier is that it coordinates with one of the channelization schemes disclosed in Part II of this disclosure.

In the channelization scheme shown in Fig. 23a, the audio component of the television signal is frequency modulated with a carrier frequency of 5.75 Mhz. That is, the audio component is placed slightly above the high-end of the video band. In particular, it is spaced 4.5 Mhz above the video carrier, thus following the convention of

standard NTSC channels.

The signals whose harmonics are likely to cause the interference described above are those with high energy, such as ringing signals, and signals relatively high in frequency such as the transient signals that occur with sudden voltage changes during hook-switching. Ordinarily, the harmonics as high as radio frequencies are harmless because the energy level of a harmonic series reduces with frequency. Because of the relatively low frequencies of the video signals, however, these harmonics may still have significant energy when reaching the same frequencies.

The ringing and transient signals originate at local exchange 476 or within telephone devices 414. To prevent this type of interference, these sources are filtered, preventing the harmonics from transmitting onto extended pairs 405. This filtering is now described.

Referring again to Fig. 22, filters 474, which include low-pass filters 474a-474e, respectively, placed in series on each of twisted pairs 476a-476e, block the harmonics of telephone signals that originate at local exchange 475 from transmission to extended pairs 405. This avoids interference with RF signals transmitting over those wires. Similarly, transients and harmonics created by the telephone devices 414 on local networks 411 are blocked from crossing over to extended pairs 405 by filtering within local network interfaces 404. That filtering is shown in Figs. 33a-33b and is described below. In the embodiments where local network interfaces 404 are not provided, other filtering must block the harmonics of telephone devices 414. This filtering is provided by the low pass filter (LPF) interposed between each of telephone devices 414 and the network wiring, as shown in Fig. 21a.

As described in Part I of this disclosure, the video signal shown in Fig. 23a may suffer from the problem of spectral tilt because it is amplitude modulated with a

picture carrier substantially below 5 Mhz. To reduce this tilt, processor 418 pre-emphasizes, or amplifies, the higher frequencies of the signal by a greater amount than the lower frequencies. This pre-emphasis is performed in processor 418 by modulators 410a-410d (collectively, modulators 410) as described below.

If pre-emphasis is not provided, or if the signal arrives at the corresponding local network interface 404 with a significant tilt despite precautions, processing in interface 404 can include means known as equalization that estimate the tilt and adjust the spectrum accordingly. Alternatively, equalization can be performed in video receivers 419 that recover signals from local networks 411 and provide them to televisions 492.

In the reverse direction, compensation for spectral tilt is implemented by providing pre-emphasis in video transmitters 417 or in local interfaces 404. Alternatively, equalization of the video signals received from extended pairs 405 can be provided in demodulators 416 of processor 418, as described below.

The preferred compensation technique for the spectral tilt of signals transmitting to local networks 411 is to perform pre-emphasis in processor 418. The preferred technique for compensation of signals transmitting in the opposite direction is to use equalization in processor 418. These techniques are preferred because using them would confine all the special compensation circuitry in a single device, transceiver/switch 400, which would seem to be economical. Also, adjustment of the compensation circuitry must normally be done for each of extended pairs 411. Thus, performing an adjustment for an entire system is more convenient when the adjustment controls are confined to one device.

<u>2) Transmitting Unmodulated Video Signals over Active Twisted Pairs (Fig. 23b)</u>

Referring to Fig. 23b, an alternative to

transmission using AM at a low frequency is to transmit the video signal in its unmodulated form. This will reduce (e.g., by 25%) the highest frequency used by the video signal below that of the previous example from 5.25 Mhz to 4 Mhz, reducing the attenuation of transmission and providing a further increase in the length over which transmission can succeed. Equally important, crosstalk energy from neighboring pairs will also decrease.

Because the unmodulated video signal occupies voiceband frequencies, telephone signals on extended pairs 405 are transmitted within a frequency band above the unmodulated video signal to prevent interference. As shown in Figs. 29b and 33b and described below, signal separators 413 (Fig. 29) and local network interfaces 404 (Fig. 30) cooperate to ensure that the telephone signals transmit above 4 Mhz on pairs 405. Fig. 23b shows the .5 Mhz band centered at 5.0 Mhz allocated to telephone signals.

Transmission of a television signal also requires, of course, transmission of audio information. As shown in Fig. 23b, the audio information transmits FM encoded at 4.5 Mhz, just above the end of the video spectrum. This is consistent with the NTSC standard. Control signals for channel selection are transmitted within a .5 Mhz band centered at 5.5 Mhz.

Provision of the telephone, control, and audio signals above the video band would seem to defeat the advantage of using unmodulated signals to reduce the maximum frequency. Because the information content of the audio and telephone signals are very low, however, these signals can be FM encoded so that the minimum SNR that they require at the receiver is much less than the 40dB required by an AM video signal. This means that the transmission length is limited by the attenuation at the upper bound (4 Mhz, in this case) of the video signal, and that distortion from crosstalk interference will be caused by crosstalk at

4 Mhz before it is caused at the frequencies used by the audio and the telephone signals.

To transmit unmodulated signals, processor 418 receives signals from communication line 402 and demodulates them, if necessary. Processor 418 then amplifies these signals, and switches a separate signal on each one of paths 478 leading to signal separators 413.

Under the proposed scheme, telephone signals from local exchange 475 that transmit over twisted pairs 476 at voiceband frequencies are converted to RF frequencies (FM, with a 5.0 Mhz carrier frequency) by signal separators 413 and fed onto extended pairs 405. Electronics within local network interfaces 404 convert the RF telephone signals back to baseband and the video signals to an RF frequency, and feed both onto local networks 411. This allows the telephone signals to be received from local networks 411 by telephone devices 414 in the ordinary manner. (Because they are at baseband, the telephone signals will pass through the low pass filter (LPF) connected between each of devices 414 and the local network wiring.)

In the opposite direction, telephone signals are fed to local networks 411 by telephone devices 414. These are intercepted by local network interfaces 404, converted to RF signals, and fed onto pairs 405 towards transmitter/switch 400. These signals are received by signal separators 413, converted to ordinary voiceband telephone signals, and fed (via filters 474) onto pairs 476 leading to local exchange 475.

Some of the details of the telephone signal processing are shown in Figs. 29b and 33b and are described in detail below. Note that local network interfaces 404 are needed to implement this scheme.

Because energy at the frequencies near DC will be attenuated much less than energy at 4 Mhz, the spectrum of the video signal is likely to tilt significantly during

transmission over extended pairs 405. The same pre-emphasis and equalization techniques described to compensate for the tilt of low-frequency AM signals can be used to adjust these baseband signals, and reduce the possibility of distortion.

3) Frequency Modulation within a Low-Frequency Channel (Fig. 23c)

In this technique, processor 418 converts each signal derived from communication line 402 to an FM waveform before transmitting the signal onto the selected one of extended pairs 405. It is preferred that the video energy be distributed between 3 Mhz and 18 Mhz, as shown in Fig. 23c. A 15 Mhz bandwidth is preferred partly because this range is sufficiently wide to ensure that the minimum SNR required at the receiver input is significantly lower SNR than that required by an AM video signal. FM transmission also provides extra protection from crosstalk interference. These benefits can justify the added expense of FM modulation in certain situations.

When extended pairs 405 are particularly long, of course, the SNR at the receiver input will be below that required by 15 Mhz FM signals. In this event, bandwidths wider than 15 Mhz can be useful because they will provide extra sensitivity, i.e., their minimum SNR level will be even lower. They do, however, suffer greater attenuation because they have energy at higher frequencies. If the greater attenuation does not defeat the extra sensitivity, bandwidths wider than 15 Mhz can extend the transmission length.

The 3-18 Mhz band is preferred above 15 Mhz bands lower in frequency because the advantage of lower bands is small. The attenuation difference, for example, between 16 and 18 Mhz is approximately .5dB per 100 ft, meaning that only a very small advantage can realized by shifting the low end of the 15 Mhz band from 3 Mhz to 1 Mhz. The advantage of the 3-18 Mhz band over a lower band of equal

width is a reduction in expense of electronics, a reduced likelihood of interference from voiceband transients, and less spectral tilt.

As shown in Fig. 23C, the audio is frequency modulated to a frequency of 20 Mhz. This frequency was chosen because it is relatively close to the high end of the video band, yet not so close to the video that sharp filtering would be required. Other frequencies, however, can also be used.

Because it requires less SNR at the receiver input, video signals encoded using FM between 3-18 Mhz (Fig. 23C) can communicate over longer distances, under some circumstances, than can be achieved using AM with a carrier below 5 Mhz (Fig. 23A). Under other circumstances, the higher frequencies required by the FM signal will more than cancel this benefit.

Following is an illustrative example. At 18 Mhz, telephone wiring attenuates a signal approximately 3.5 dB per 100 feet. That means that the energy at the high end of the FM signal will be 10.5 dB lower after being transmitted 300 feet over an extended pair 405. The attenuation of energy at 4.5 Mhz, which is near the high end of the AM signal (Fig. 23A) or the unmodulated signal (Fig. 23B) is approximately 3 dB over the same path (i.e., 1 dB per 100 feet). Thus, after 300 feet, the level of the FM signal of Fig. 23C will be 7.5 dB lower than either of the signals of Figs. 23a or 23b.

Because of its higher sensitivity, however, the level of the FM signal need only exceed the noise by 30 dB, while AM and unmodulated signals should have an SNR of at least 40 dB. Thus, when first fed to the transmission line, the AM signal will 10 dB closer to its minimum required level, which is approximately 0dB mV for most receivers. Assuming the signals are fed at 30 dB mV, the high end of the FM signal will be at 19.5 dB mV after 300

feet, while the high end of the AM signal will be at 27 dB mV. Thus, FM will still have an advantage, meaning it can tolerate, for example, more broadcast interference. The advantage, however, has reduced to 2.5 dB, i.e. the advantage of 10 dB has been eroded by an amount of 7.5 dB. This advantage will disappear at a transmission distance of 400 feet.

Now consider the situation where local network interfaces 404 are not provided and the transmission path includes 200 feet on extended pairs 405 and 100 feet on the part of the local networks 411 that leads to video receivers 419. In this situation, the attenuation of transmission will be the same but splits may be encountered along the final 100 feet (i.e., the portion of the transmission path that includes a local network 411). Because each split causes 3.5 dB of attenuation, if 8 spits are encountered, the FM signal will be at -8.5 dB mV, above its requirement of -10 dB mV, while the AM signal will be at -1 dB mV, below its minimum.

Independent of the transmission path length, the FM signals will be more resistant to crosstalk interference than AM video signals. At 15 Mhz, for example, the crosstalk loss within a 25-pair bundle of wires varies between 25-50 dB, according to measurements made by the inventors. (As explained above, crosstalk loss is the energy loss, in dB, suffered by a signal while broadcasting across to neighboring wires.) Thus, if signals transmit over ten neighboring pairs at similar levels, the interfering energy contributed by each pair will be 25-50 less than the signal of interest, and the total interfering energy will be 10dB higher, or 15-40 dB less than the signal of interest. (This assumes that the interfering signals are incoherent because they originate from different sources. The final paragraphs of this section discuss the situation where the

interfering signals are all the same, i.e., coherent.) FM video signals with a 15 Mhz bandwidth, however, can have a capture ratio of approximately 10dB, eliminating crosstalk as a problem in nearly all cases.

At 5 Mhz, on the other hand, which is the approximate upper frequency of the AM signals (Fig. 23A), crosstalk loss varies between 30-60 dB. Because AM signals require at least 40 dB SNR, there is a good possibility that this energy will cause interference with the AM signals at that frequency.

<u>4) Coherent Addition of Crosstalk Energy from Identical Signals Transmitting over Several Pairs at Once</u>

A particular type of crosstalk interference can occur when transmitting signals over several twisted pairs in a large bundle of pairs. Specifically, if the signals transmitting over a large group of pairs in a bundle are identical, and one particular pair outside that group carries a different signal, then the energy in the multiple pairs may "add coherently" onto the single pair, causing more interference that would occur if all pairs carried different signals. Such a situation is likely to occur when a group of signals is made freely available for selection by users at several local networks served by the same bundle. (i.e., when the signals on communication line 402 are not targeted specifically for one of the units.) In that event, this problem can occur when the popularity of one signal dominates the others.

An example is where a coaxial cable is brought to the basement of an apartment building, and transceiver/switch 400 derives signals from that cable, offering any one of 30 video signals to the units therein by transmission over the telephone wires that lead to the units. Assume there are 25 units in the building, and 10 of those units select a first video signal. An eleventh unit selects a second video signal. Assuming crossover

loss from any of the ten pairs to the eleventh pair is 30 dB, and the contributions from the ten pairs add coherently, the total amount of interfering energy on the extended pair carrying the second signal will be only 10dB below the level of that second signal, or 20 dB higher than the interference from any one of the ten pairs carrying the first signal. Thus, even if FM is used, there is a high likelihood of interference with the second signal in this situation. (If the signals added incoherently, i.e., if all units in the group of ten selected different signals, the total interfering energy would be 20dB below the signal of interest.)

Below we describe a technique which can reduce the increase in crosstalk interference which occurs in this situation. This technique is embodied in signal separators 413 and shown in Figs. 29a and 29b.

F. Signal Processing, Conversion, and Switching in Transceiver/Switch 400 (Figs. 24-27)

As described above, conversion and switching of signals in transceiver/switch 400 is accomplished by interface processor 418 (Fig. 24) and control signal processor 420 (Fig. 27). Processor 418 serves as the interface between transceiver/switch 400 and communication line 402, and also as the interface between different ones of extended pairs 405. Each of signal separators 413 serves as the interface between transceiver/switch 400 and an associated one of extended pairs 405. As such, one of the functions of processor 418 is to select and recover video and other types of signals from communication line 402, change the characteristics of the recovered signals through processing, and apply them to signal separators 413 for transmission to local networks 411 via extended pairs 405. Another function of processor 418 is to receive video and other types of signals from signal separators 413, process those signals, and transmit them to communication line 402. A third function of processor 418 is to apply

signals received from one of signal separators 413 to a different one of signal separators 413.

As emphasized earlier, no processing (such as modulation, demodulation, or frequency shifting) of the signals destined for one of local networks 411 takes place after output from processor 418 (along paths 478) and before reaching local network interfaces 404. Thus, the signal processing performed by processor 418 on the individual signals it selects and recovers from communication line 402 determines the waveform, frequency, and amplitude at which these individual signals will be transmitted across extended pairs 405. This processing is discussed below.

Control signal processor 420 receives control signals transmitted onto local networks 411 (by IR control devices 493) that are targeted for master controller 415, and it also receives control signals from communication line 402. As described above, processor 420 converts the control signals to a form that can be interpreted by master controller 415, and then passes the resulting signals to controller 415. Master controller 415 uses those signals to determine, among other things, which signals shall be selected from communication line 402, and which of local networks 411 shall be targeted to receive those signals. This processing is described in detail below.

A detailed description of a preferred embodiment of interface 418 is given in the following paragraphs, followed by a description of a preferred embodiment of control signal processor 420. It will be appreciated, however, that processor 418 can take on many different embodiments, as long as it fulfills the following three functions (which are also described above):

1) recover video and other signals from communication line 402, and transmit separate electrical signals, including combinations of the recovered signals, onto each of paths 478 that lead to signal separators 413;

2) receive signals transmitted from signal separators 413 along paths 479, process these signals, and apply them to communication line 402;

3) receive signals transmitted from signal separators 413 along paths 479, process these signals, and apply them to other signal separators 413.

There are many ways that processor 418 can be implemented to fulfill these functions. Indeed, the closed circuit TV industry provides a large variety of electrical and optical processing devices that couple video signals, split video signals, modulate and demodulate signals, and shift signals in frequency. What is shown herein is a method that is preferred in this application, as well as several alternatives.

1) Processor 418 (Fig. 24)

Referring to Fig. 24, processor 418 includes interface 409, signal distribution subsystem 403, and signal collection subsystem 407. Interface 409 performs two functions. One is to receive signals from communication line 402 and feed them to subsystem 403 in electrical form, independent of the form at which these signals transmit across line 402. (Thus, interface 409 can receive optical signals from communication line 402.) The other function is to receive electrical signals from signal collection subsystem 407 and to apply them to communication line 402, independent of the mode (i.e. electrical, optical, or other) of line 402. (That is, if line 402 is a fiber optic medium, interface 409 converts electrical signals from sub-system 407 to light signals.)

There are many examples of devices that perform such a function. Some of these are designed to interface between an optical line and an electrical communication system. One embodiment of interface 409 is shown in Fig. 24a, and is an example of an interface between a coaxial communication line 402 and an electrical system. It includes circulator 421, block converter 423, and block

converter 447.

Circulator 421 receives energy from line 402 and transmits it to block converter 423 while isolating the received energy from block converter 447. Circulator 421 also receives signals from block converter 447 and applies them to communication line 402 while isolating block converter 423 from these signals.

Block converter 423 selects a particular frequency band from its input signal and shifts it in frequency, transmitting the result to signal distribution subsystem 403. This is done in two steps. First, all input signals are heterodyned 423a, 423b to shift the selected band to the output band. Then, the shifted signal is transmitted through the output filter 423c and passed to subsystem 403. As described later on, subsystem 403 transmits the signals received from interface 409 to signal separators 413.

Following is an example. Video signals between the frequencies of 54 Mhz and 900 Mhz transmit from line 402 through circulator 421 to block converter 423. Converter 423 performs a fixed downshift using a preset heterodyne frequency of local oscillator (L.O.) 423b of 620 Mhz, shifting the band between 650-700 MHz to the band between 30-80 Mhz. The result is passed through a filter 423c that only passes energy between 30-80 Mhz. Thus the frequency band between 650-700 MHz is selected and converted to the band between 30-80 Mhz. All other frequencies in the 54 MHz to 900 MHz band are rejected.

Selection and conversion of a frequency band from communication line 402 in the manner described above can be useful when certain frequency bands on a high capacity line are "reserved" for communication with a group of networks. Using the example above, communication line 402 can serve a neighborhood with includes many residences, with the frequencies between 650-700 being dedicated to communication with the residences corresponding to the five

local networks 411.

Interface 409 also receives a signal from signal collection subsystem 407. This electrical signal, which may include several individual signals combined together, transmits to block converter 447. The frequency shifter 447a, L.O. 447b, and band pass filter 447c in block converter 447 combine to shift this signal to the frequency at which it will transmit across line 402, and amplifier 447d amplifies the result. Finally, block converter 447 transmits this signal through circulator 421 and onto communication line 402.

Following is an example. Video transmitter 417b receives a signal from video camera 494b (Fig. 21a), converts it to a single 20 Mhz FM video signal between the frequencies of 20-40 Mhz, and transmits it onto local network 411b. This signal is amplified by local network interface 404b and transmitted across extended pair 405b. At transceiver/switch 400, the signal transmits to signal separator 413b (Fig. 22). That component directs the signal to signal collection subsystem 407. Video transmitter 417c feeds a second video signal across extended pair 405c to subsystem 407 using a similar process. Using techniques described below, subsystem 407 converts these two signals to AM video signals within adjacent 6 Mhz channels between 120-132 Mhz. These signals are transmitted over the same conductive path to block converter 447, which upshifts them to the band between 1000-1012 Mhz, and transmits them through circulator 421 to communication line 402.

Signal distribution subsystem 403 receives the electrical signals from block converter 423 and, under control of master controller 415 (via links 446a-446c), selects some of the individual signals contained therein. Subsystem 403 then creates several different combinations of the selected signals. Specifically, a different group

of selected signals is combined and applied to each of the conductive paths 478. Furthermore, each selected signal is converted to the frequency, waveform, and amplitude at which it will transmit across one of extended pairs 405. (This conversion also assures that the selected signals in each group do not overlap in frequency.) These signals transmit to each of signal separators 413. (As described above, there is a one-to-one correspondence between signal separators 413 and paths 478.) Several embodiments of this selection and combination process are described below. Examples of the signal processing of subsystem 403 will be given following these descriptions.

Signal separators 413 transmit the signals received from signal distribution subsystem 403 onto the corresponding one of extended pairs 405. Thus, interface 409 and distribution subsystem 403 cooperate to determine which signals transmit from communication line 402 to local networks 411.

In addition to selecting and distributing signals, signal distribution subsystem 403 also splits the signal received from interface 409, providing that signal to control signal processor 420 over path 420b. This allows processor 420 to detect signals from communication line 402 that are intended to communicate with master controller 415. As will be described below, processor 420 selects specific signals from path 420b by demodulating the energy within a specific frequency band. It then processes the resulting signal, and feeds it to master controller 415.

Except for control signals that provide communication with master controller 415, subsystem 407 receives all non-telephone signals that signal separators 413 receive from extended pairs 405. (Non-telephone signals are those not intended to communicate with local exchange 475.) These signals transmit from signal separators 413 to subsystem 407 along paths 479. Subsystem 407 selects

particular signals from among those arriving on paths 479 and combines them onto a single conductive path. (Before combination, signals may be shifted in frequency to prevent them from overlapping in frequency and to arrange them within adjacent channels for application to communication line 402.) This combined signal is transmitted to interface 409, as described above.

A detailed description of several embodiments of signal distribution subsystem 403 and signal collection subsystem 407 is presented next.

2) <u>Signal Distribution Subsystem 403a (Fig. 25a)</u>

Signal distribution subsystem 403a, one preferred embodiment of signal distribution subsystem 403, is shown in Fig. 25a. As described above, interface 409 transmits signals along a single conductive path leading to signal distribution subsystem 403a. Internal to subsystem 403a, these signals transmit to splitter 426′, which splits the signal energy along several conductive paths. Four paths are contemplated in Fig. 25a. Three paths lead to demodulators 426a-426c, (collectively, demodulators 426). The fourth path, labelled path 420b, leads to signal processor 420.

Processing of the output of splitter 426′ by demodulators 426 is described in the following paragraphs. Processing of this output by control signal processor 420 is described further on in this disclosure.

Each demodulator 426 (details are shown for demodulator 426c only) selects one signal from among those applied by block converter 423, and converts that signal to baseband. The selection and conversion process conducted by demodulators 426 is similar to that performed by ordinary cable converters that have baseband outputs. As shown in Fig. 25a, the input signal is frequency shifted by multiplication with the output frequency of a local oscillator. (A local oscillator is denoted by "l.o." in

the figures of this disclosure.) The local oscillator frequency is tuned to bring the selected signal to an intermediate channel. The shifted signal is then filtered, isolating the intermediate channel. Finally, this signal is demodulated, generating the selected signal at baseband.

The identity of the signal selected by demodulators 426 is determined by master controller 415. That component implements its control by sending signals along link 446a to each of demodulators 426. These signals determine the frequency of the local oscillators of those components, thus determining which signals are brought to the intermediate channel by each demodulator 426. Ordinary techniques that achieve digital communication between two components on an electronic circuit board can suffice for link 446a.

Under an alternative embodiment, the selection of an individual signal from communication line 402 is predetermined by the hardware instead of falling under the control of master controller 415. This can be done simply by designing or manually adjusting demodulators 426 to demodulate only signals within a specific channel. Selection is then determined at the "headend" by feeding the desired signal onto line 402 at the channels to which demodulators 426 are tuned. For example, assume that communication line 402 is a cable TV feed and that 100 NTSC video signals pass through circulator 421 to block converter 423 in interface 409a. Assume further that block converter 423 selects the 10 adjacent signals beginning at 300 Mhz and converts them to the 10 adjacent 6 Mhz bands between 108 Mhz and 168 Mhz. Now let demodulator 426a be designed to always select the video signal expressed between 108 and 114 Mhz, whatever that signal may be. In this situation, the identity of the signal selected by demodulator 426a is determined at the "headend," or root of the cable TV feed. Specifically, whatever signal is fed

between 300-306 Mhz at the root will be selected and provided as output by demodulator 426a.

The basebanded signals output by demodulators 426 constitute the signals "selected" for distribution to local networks 411. (They are labelled the "selected" signals in Fig. 25a.) They will pass through separators 413 to extended pairs 405. First, however, they are converted to the waveform, frequency, and energy level at which they will be transmitted across extended pairs 405. This is accomplished by modulators 410a-410d (collectively, 410).

Each modulator 410 (the details of modulator 410d are shown) is designed or manually adjusted so that it always modulates its input in the same manner, outputting it within the same frequency band and at the same energy level. Thus, each of modulators 410 corresponds to a different "channel" used by signals that transmit across extended pairs 405. To provide flexibility in assigning any one of the signals selected by demodulators 426 to any of the channels created by modulators 410, signals from demodulators 426 transmit to modulators 410 through switch 462a. Thus, switch 462a assigns the selected signals to different channels.

Switch 462a works as follows. Internal to switch 462a are splitters 435a-435c (collectively, splitters 435), which have a one-to-one correspondence with demodulators 426. As shown in Fig. 25a, each of the signals from demodulators 426 transmits to splitters 435 which splits the energy of the signals onto four paths, each one leading to a different one of switching banks 448a-448d (collectively, banks 448). Each bank 448 responds to signals sent from master controller 415 along link 446b. In response to these signals any one of banks 448 can switch any one of its inputs to any or all of modulators 410a-410d. Thus, switch 462a can provide each of modulators 410 with the outputs of any demodulator 426.

Because the outputs of demodulators 426 are all at baseband, however, master controller 415 ensures that at most one signal (i.e., the output of only one demodulator 426) is provided to any one of modulators 410 at one time. Some of modulators 410, however, may not receive signals.

As described above, each modulator 410 converts the baseband signal it receives to a particular waveform, frequency, and energy level. The signals output by modulators 410 do not undergo further processing (modulation or frequency shifting) before exiting subsystem 403. As described earlier, the waveform, frequency, and energy level of signals output by subsystem 403a is very important because these signals ultimately transmit to extended pairs 405 without any further processing except for filtering and switching. Thus, the processing applied by modulators 410 determine, to a large extent, the reliability of transmission to local networks 411.

As described in Part I of this disclosure, when AM signals are transmitted with a picture carrier below 5 Mhz, spectral tilt is likely to cause distortion. One of the proposed solutions is to "pre-emphasize" the high frequencies of the signal so that the attenuation related to transmission will result in reception of a signal with a flat spectrum. It is preferred that this pre-emphasis be performed within modulators 410. Following is an example of how pre-emphasis can be implemented within modulator 410a.

Assume that modulator 410a outputs an AM NTSC video signal with a picture carrier at 1.25 Mhz (Fig. 23a). The upper sideband of such a signal will extend approximately between 1.25 Mhz and 5.25 Mhz. Assume that attenuation of extended pair 405b at 1.25 Mhz is 1 dB per 100 feet, and at 5.25 Mhz it is 3 dB per 100 feet. (Assume further that the affect of attenuation follows, to a good approximation, a linear variation between those endpoints.) If extended

pair 405b is 1000 feet long, and the signal from modulator 410a is to be applied to pair 405b, the energy at 5.25 Mhz would ordinarily be received at a level 20 dB lower than that at 1.25 Mhz. To compensate for this, processor 410a can include circuitry to "pre-emphasize" the signal such that energy at 5.25 Mhz is transmitted 20dB higher than that at 1.25 Mhz, and such that the pre-emphasis varies approximately linearly between those frequencies. Such pre-emphasis circuitry is known.

It is preferred that the modulation process follow any pre-emphasis process. This sequence is shown in the block diagram of modulator 410d (Fig. 25a). If AM waveforms are used, the modulation process involves mixing or multiplying the frequency of the signal by a local oscillator. If FM waveforms are used, the modulation process involves "encoding" voltage variations of the signal as frequency deviations of the carrier. After modulation, the signal is filtered and amplified to the level at which it will transmit across the wiring.

Each signal produced by modulators 410 transmits through switch 401 over one or more of paths 478 to signal separators 413. (Paths 478 have a one-to-one correspondence with signal separators 413, and thus with extended pairs 405 and local networks 411.) Switch 401, which responds to commands from master controller 415 sent over link 446c, is implemented in the same manner as switch 462a. Master controller 415, however, allows switch 401 to apply the output of more than one modulator 410 onto any one of paths 478a-478c. Thus, switch 410 "composes" the signal sent to each of signal separators 413 by combining the outputs of modulators 410. The only restriction is that the signals from two of modulators 410 that overlap in frequency cannot be switched onto the same one of paths 478. The signals output by switch 401 are labelled "distributed signals" in Fig. 25a.

3) Signal Collection Subsystem 407a (Fig. 26a)

Signal collection subsystem 407a, one preferred embodiment of signal collection subsystem 407, is shown in Fig. 26a. Signals received by subsystem 407a arrive along paths 479 and transmit to amplifiers 408a-408c (collectively, amplifiers 408). These signals originate on local networks 411.

Following is an example of the transmission path followed by a signal received by subsystem 407a. Signals fed by video transmitter 417b to local network 411b are received by local network interface 404b and retransmitted onto extended pair 405b. These signals transmit across pair 405b to signal separator 413b. As is described later on, signal separator 413b separates out the telephone signals and passes the remaining signals to amplifier 408b. Equivalent paths are used by other RF transmission devices to send signals to amplifiers 408a and 408c.

The output of each amplifier 408 passes through switch 429 to demodulators 416a-416d (collectively, demodulators 416). Amplifiers 408 are provided to compensate for the energy loss caused by signal splitting internal to switch 429.

The design of switch 429 follows that of switch 462a in Fig. 25a. As such, switch 429 responds to commands from master controller 415. These signals are sent over link 446d.

Each demodulator 416 selects a channel (i.e. a frequency band) from its input signal and converts the energy in that band to baseband frequencies. As shown for demodulator 416a, the demodulation procedure involves frequency shifting a selected frequency band to an intermediate band, filtering that band, and demodulating the result. Equalization of the signal to compensate for spectral tilt is also performed, if necessary. In the case of AM signals, it is preferred that the equalization be

done after demodulation. In the case of FM signals, equalization should be done before demodulation but after filtering. The purpose of equalizing FM signals before demodulation is described in Part I of this disclosure. (This equalization process is not to be confused with the process called "emphasis" which is part of standard FM communication. In this process, the level of the higher frequencies of the information signal are amplified before modulation, and then attenuated after demodulation. This compensates for the tendency, inherently part of FM communication, whereby noise affects the higher frequencies of a signal more than the lower frequencies.)

The demodulation process creates a basebanded version of the signal in the selected band. Selection of channels by demodulators 416 is done by altering the frequency of the local oscillator (l.o.) used to implement frequency shifting. This frequency is set in response to control signals from master controller 415 transmitted over link 446e.

The output of each demodulator 416 constitutes the signals "collected" from local networks 411. These signals are passed to modulators 428a-428d (collectively, modulators 428), which have a one-to-one correspondence with demodulators 416. As is described below, modulators 428 perform the first step in "exporting" signals by applying them to communication line 402.

As is also described below, in embodiments in which local networks 411 transmit video signals to each other, signal distribution subsystem 403b (Fig. 25b) is used in place of subsystem 403a, and the "collected" signals are passed along paths 488a-488d (collectively, paths 488) to signal distribution subsystem 403b. Subsystem 403b can transmit each signal received from paths 488 to a local network 411 that is different from the local network that originated the signal.

By controlling switch 429 and demodulators 416, master controller 415 determines which of the signals input to amplifiers 408 are "collected," i.e. output from one of demodulators 416. Note that switch 429, because it follows the design of switch 462a, can simultaneously connect the output of every amplifier 408 to any number of demodulators 416. This is important if the signal provided by one of amplifiers 408 includes more than one independent signal. For example, if the energy output by amplifier 408b includes two adjacent 6Mhz NTSC video signals between 6-18 Mhz, and the output of amplifier 408b can be switched to both demodulators 416b and 416c, both video signals can be "collected." Note that none of demodulators 416 can receive the output of more than one of amplifiers 408, even if the two output signals do not overlap in frequency. Such switching would not make sense because demodulators 416 select only one signal at a time.

As described earlier, modulators 428 implement the first step in applying the outputs of demodulators 416 to communication line 402. Specifically, each of modulators 428 receives the single basebanded signal output by the corresponding one of demodulators 416. As shown in Fig. 26a, the process includes mixing the frequency of a local oscillator (l.o.) with that of the input signal, and filtering the output. This process creates a new signal, with identical information content, within an RF frequency band.

The local oscillators used by each of the modulators 428 are such that the resulting output frequency bands do not overlap. This allows the outputs to be combined onto a single conductive path. In a preferred embodiment, the frequency bands confining the outputs of modulators 428 are adjacent in addition to being non-overlapping. This minimizes the width of the band occupied by the combined signal.

The signals output by modulators 428 are all transmitted to coupler 428′. That component combines the individual signals onto a single conductive path, and passes it to interface 409. That component applies the combined signal onto communication line 402, as described above.

4) Control Signal Processing (Fig. 27)

Referring to Figure 27, processor 420 includes filters 427a-427c and 427z (collectively, filters 427), demodulators 443a-443c and 443z (collectively, demodulators 443), and digitizer 436.

As described above, control signals generated by individual control devices 493 and targeted for master controller 415 are transmitted onto local networks 411 by video receivers 419, received by interfaces 404, and fed to extended pairs 405. The control signals are recovered from extended pairs 405 by signal separators 413 and routed to control signal processor 420 along paths 477, which have a one-to-one correspondence with signal separators 413. The control signals arrive at processor 420 at the frequency and waveform at which they were fed to extended pairs 405.

Control signals from communication line 402 also transmit to processor 420. These signals are transmitted from signal distribution system 403 along path 420b (Fig. 24).

As seen in Fig. 26, path 420b connects to filter 427z, while signals transmitting over paths 477 present at corresponding filters 427a-427c. Filters 427 restrict the frequency of the signals passing to the corresponding demodulators 443 to the bands used by the control signals targeted for master controller 415. Signals passing through filter 427z are received by demodulator 443z, while signals passing through filters 427a-427c are received by demodulators 443a-443c.

Demodulators 443a-443c and 443z convert such

received signals to baseband frequencies, and pass the results to digitizer 436. That device converts the basebanded signals to digital signals, and passes them to master controller 415 over path 420a. Common methods for communicating digital information between two components on a circuit board can suffice for this link. Methods of digitizing and communicating control signals originating from infrared transmitters are described in detail in Part II of this disclosure.

5) Example #1

Referring to Figs. 21a, 22, 24, 24a, 25a, 26a, and 27, the following is an example of the processing of non-telephone signals in transceiver/switch 400. Assume that line 402 is a fiber optic cable transmitting high frequency optical impulses that represent frequency modulated encoding of a group of signals with a bandwidth of 5,000 Mhz. Among the individual signals expressed in the 5,000 Mhz band are 50 standard amplitude modulated NTSC signals confined within adjacent 6 Mhz channels. These are expressed between the frequencies of 2000 Mhz and 2300 Mhz.

One of the functions of the communication system of this invention is to transmit any of the individual signals expressed between 2000-2500 Mhz on demand to video receivers 419 and transceiver 491c connected to local networks 411a-411c. Furthermore, the system must allow the users to indicate their video selections by using infrared remote control transmitters 493a, 493b, and 493c shown in Fig. 21a.

Communication line 402 also accommodates communication of signals in the opposite direction, away from transceiver/switch 400. A second task of the communication system is to allow video transmitters 417 and transceiver 491c to transmit signals onto line 402.

The light impulses from communication line 402 are received by interface 409. That component responds to

these impulses by producing a frequency demodulated electrical version of the 5000 Mhz signal encoded therein. Block converter 423 in interface 409a selects the frequencies between 2000 Mhz and 2500 Mhz, and converts them to voltage variations between 100 Mhz and 600 Mhz.

The 500 Mhz wide, composite electrical signal provided by interface 409 is transmitted to splitter 426′ in signal distribution subsystem 403a. Splitter 426′ splits the input energy four ways, transmitting the signal to demodulators 426 and also along path 420b to control signal processor 420.

Referring also to Fig. 28, demodulators 426 react in the following manner. In response to signals fed from master controller 415 over link 446a, demodulator 426a selects and basebands the signal between 176 Mhz and 182 Mhz (video signal U). Similarly, demodulator 426b selects and basebands the 6 Mhz AM signal between 188-194 Mhz (video signal V), and demodulator 426c selects the signal between 200-212 Mhz, which is a digital signal conforming to the "10BaseT Ethernet" standard (digital signal Y), and converts it to a demodulated signal at baseband. Thus, two ordinary NTSC video signals are selected from line 402, basebanded, and provided to switch 462a along two separate conductive paths. A third conductive path provides a 12 Mhz wide computer signal.

Switch 462a applies the output of demodulator 426a (video signal U) onto the path leading to modulator 410a, the output of demodulator 426b (video signal V) onto the paths leading to modulators 410b and 410d, and the output of demodulator 426c (digital signal Y) onto the path leading to modulator 410c.

Modulators 410 modulate their input signals, converting them to frequency bands between 1 Mhz and 22 Mhz. These are the frequencies used to transmit signals from transceiver/switch 400 to local networks 411.

Specifically, modulators 410a and 410b amplitude modulate video signals U and V, respectively, to produce RF signals at 40dB mV between 1-6 Mhz in each case. (The frequency band between 1 and 6 Mhz can be used to provide a standard 6 Mhz NTSC channel if the part of the lower vestigial sideband between 0-1 Mhz is filtered out. This technique is described in Part II of this disclosure.) Modulator 410d, on the other hand, converts video signal V to an FM signal at 40dB mV between 7 and 22 Mhz, and modulator 410c converts digital signal Y to a signal confined between 6 and 18 Mhz. Switch 401 receives the outputs of modulators 410a-410c and applies them to paths 478a-478c, respectively. Switch 401 also applies the output of modulator 410d to path 478a and couples the output of modulator 410b onto path 478c. Thus, path 478a conducts both video signal U and video signal V (in different frequency bands), path 478b conducts video signal V, and path 478c conducts both video signal V and digital signal Y (in different frequency bands).

The signals applied to paths 478a-478c transmit to signal separators 413a-413c, respectively. Those components feed the signals onto extended pairs 405a-405c, respectively, using techniques described below.

The signals transmit across pairs 405a-405c to local network interfaces 404a-404c, respectively, each of which converts the signals as necessary to enable them to be transmitted over respective local networks 411a-411c. Specifically, local network interface 404a converts video signal V to an AM signal in the frequency band between 24-30 Mhz and video signal U to an AM signal in the frequency band between 12-18 Mhz. Meanwhile, local network interface 404b converts video signal V to an AM signal in the frequency band between 54-60 Mhz (corresponding to VHF channel 2). Finally, local network interface 404c converts video signal V to the AM signal between 12-18 Mhz, and

expresses digital signal Y between the frequencies of 18-40 Mhz. Techniques to perform these conversions are described below.

After this conversion, local network interfaces 404 amplify the signals and retransmit them onto the respective local networks 411. Once applied to local networks 411, signals U, V, and Y are received by video receivers 419 and transceiver 491c. Video receivers 419 convert signals V and U to tunable frequencies before transmitting them to connected televisions 492, and transceiver 491c converts its signal to a form appropriate for computer 495c. Video receivers 419a and 419a', in particular, apply a single upshift of 186 Mhz to energy between the frequencies of 12 Mhz and 30 Mhz, converting signals U and V to video signals with picture carriers at 199.25 and 211.25 Mhz, (i.e. VHF channels 11 and 13), respectively. A design for a video receiver that performs such a block conversion is given in Part II of this disclosure, and a design for transceiver 491c is given in Part I of this disclosure. These conversions allow users at local networks 411a and 411b to watch video signal V, those at local network 411a can also watch video signal U, and computer 495c at local network 411c can receive digital signal Y, which is an "EtherNet" signal from communication line 402.

Meanwhile, RF transmitters 417 connected to local networks 411 apply signals to those networks that transmit in the opposite direction. These are received by interfaces 404, which in turn apply them to pairs 405. The signals then transmit to signal separators 413 in transceiver/switch 400. Those components direct the signals along paths 479 to amplifiers 408 in collection subsystem 407a of processor 418. All of these signals transmit across extended pairs 405 at frequencies between 24 and 100 Mhz, a band that does not overlap with the band in which signals transmit in the opposite direction (i.e.,

1Mhz - 22Mhz).

(Techniques embodied in local networks interfaces 404 that receive signals from local networks 411, convert them, and transmit them across extended pairs 405 are described below. The routing of these signals by signal separators 413 is also described below.)

An example of the signals transmitted by the RF transmitters 417 connected to local networks 411 and the conversions performed by local network interfaces 404 follows. Assume that video transmitter 417b inputs an NTSC video signal (video signal W) from camera 494b and feeds it onto local network 411b amplitude modulated between 6-12 Mhz. This signal is received by local network interface 404b, converted to an FM signal between 24-54 Mhz, amplified, and applied to extended pair 405b. At transceiver/switch 400, video signal W transmits to signal separator 413b, which applies it to amplifier 408b. Meanwhile, video signal X is generated by camera 494c and transmits from video transmitter 417c to amplifier 408c in an identical manner (via interface 404c, extended pair 405c, and signal separator 413c).

Transceiver 491c, meanwhile, receives a digital signal from computer 495c. That signal carries 1 Mbits/sec of information, (less than digital signal Y) and is called digital signal Z. Transceiver 491c expresses this signal between 1-6 Mhz, and applies it to local network 411c where it is intercepted by local network interface 404c. Interface 404c encodes this signal using frequencies between 54-100 Mhz and transmits it onto extended pair 405c. The signal transmits across to transceiver/switch 400. Because it is expressed at relatively high frequencies, signal Z is received with a lower SNR, but its wider bandwidth allows reception with a low error rate. At transceiver/switch 400, digital signal Z transmits through signal separator 413c to amplifier 408c.